



Spatio-temporal patterns of climate parameter changes in Western Mediterranean basin of Türkiye and implications for urban planning

Oznur Isinkaralar¹

Received: 15 September 2022 / Accepted: 10 August 2023 / Published online: 29 August 2023
© The Author(s), under exclusive licence to Springer Nature B.V. 2023

Abstract

In today's world, where the effects of climate change can be easily monitored, determining the resilience of cities and regions against climate crisis is a fundamental research area in terms of planning approaches. While producing spatial planning decisions, the effects of climate change should be analyzed in terms of time and integrated into the process. While the research reveals the change of spatial bioclimatic comfort zones according to climate change scenarios, it criticizes the position of planning practice within the framework of planning theory and a comprehensive planning approach. The research is carried out on the scale of the Western Mediterranean basin, one of the hot climate regions of Türkiye. The change between 2020 and 2100 is spatially revealed via the climate change scenarios. SSP 245 and SSP 585 are selected for this purpose. Discomfort Index (DI) and Effective Temperature-Taking Wind Velocity (ET_v) techniques were used to classify bioclimatic comfort zones. As a result of the research, while the most common (20%) areas are between 16 and 18 °C, the most common temperature range rises to between 25% and 22–24 °C, according to SSP 585. According to DI simulations, 43% of the area is comfortable, and 38% is in cold areas. According to SSP 245, in 2100 forecasts, cold areas decrease to 9%, and hot areas that were not previously present occupy 13%. According to SSP 585, on the other hand, cold areas decrease to 2%, while hot areas reach 41%. With a more optimistic approach, the ET_v index changes from a character dominated by slightly cool areas (35%) to mild (43%) and comfortable (26%) areas compared to SSP 585. However, some warm (7%) and quite hot (1%) areas do not exist. The increase in hot areas in the country, including coastal settlements with high tourism potential, is striking. While the research reveals the change of spatial bioclimatic comfort zones according to climate change scenarios, it criticizes the position of planning practice within the framework of planning theory and a comprehensive planning approach. Today, the position of spatial planning decisions based on long-term decisions in the country's legislation is discussed in the context of the climate crisis.

Keywords Climate change · Urban modeling · Greenhouse gases · Climate crisis · Regional change

Introduction

Globally, governments and societies are tackling vital challenges accelerated by intense human activities, such as air pollution (Kumar and Pande 2023; Sulhan et al. 2023; Zhang et al. 2023), traffic (Su et al. 2022), social problems (Xiao et al. 2022), and climate change (He et al. 2022). Climate parameter changes are one of the biggest transnational problems that countries are struggling with today

(Melidis and Russel 2020; Cifuentes-Faura 2022). In the 20-year period up to 2020, the global surface temperature increased by 0.99 °C compared to the 50-year period up to 1900 (Masson-Delmotte et al. 2021; Nita et al. 2022). The direct and indirect effects of the problems have been a considerable concern worldwide (Isinkaralar 2022; Kumar and Pande 2023). The global order formed by the interaction of complex systems encompasses several features, such as the diversity of possibility spaces and the butterfly effect (Renn and Lucas 2022; Isinkaralar and Varol 2023). As a complex system, cities do not show linear development and have a self-organizing feature. Many studies highlight the complex relationships in various dynamics and urban growth by emphasizing the nonlinear nature of urban processes (Sohail et al. 2021; Shu et al. 2021; Isinkaralar et al.

✉ Oznur Isinkaralar
obulan@kastamonu.edu.tr

¹ Department of City and Regional Planning, Faculty of Engineering and Architecture, Kastamonu University, Kastamonu 37150, Türkiye

2022; Wang 2022). However, it may be subject to certain losses until it reaches equilibrium against possible shocks, extreme events, and fluctuations. The stance of urban planning against economic and vital risks is an essential area of theoretical discussion. Considering the risks arising from the impact of climate change, today's urban infrastructure should be re-evaluated, and risk profiles should be analyzed in terms of urban management (Castán Broto and Robin 2021; Twinomuhangi et al. 2021).

The Intergovernmental Panel on Climate Change (IPCC) offers many quantitative ideas about current processes (Wardekker and Lorenz 2019). Governments must foresee the possibilities of the climate crisis, such as high temperatures, excessive precipitation, drought, floods, storm waves/coastal floods, sea level rise, and environmental health risks (Hazra et al. 2022). Traditional location theory, planning theory, and comprehensive planning do not have a defense mechanism against unexpected events (Ramyar et al. 2021). The primary purpose of city planning is to make cities more livable in many dimensions (Nicolas et al. 2021; Yi et al. 2021; Browning et al. 2022; Kang et al. 2022; Mouratidis and Yiannakou 2022). However, the long-term targets and development decisions produced while doing this do not offer flexibility against the dynamics brought by climate risk. Floods and forest fires occur in many regions worldwide (Grigorieva and Livenets 2022; Jasour et al. 2022). However, fragmented action plans are produced after the event, and losses occur. Therefore, long-term predictions and planning decisions based on today's climate indicators are very utopian. In addition, while producing plan decisions, temporal bioclimatic parameters lag behind criteria such as slope, land cover, and ownership in terms of weight. Many studies have emphasized that bioclimatic comfort is a crucial prerequisite for livable environments, considering the effects of thermal comfort and microclimate (Mansuroğlu et al. 2021; Dogan et al. 2022).

Climate-resilient city scenarios and the flexibility required by decisions to deal with uncertainties and possibilities are gaining academic and political significance in the fight against climate risk. Many researches are carried out with administrative and economic dimensions to determine the vulnerability levels of cities and to provide resilience (Berke et al. 2021; Giri et al. 2021; He et al. 2021; Yang et al. 2021). Research that emphasizes vulnerability and demonstrates the need for pre-hazard measures is widespread. Current studies on measuring vulnerability levels also draw attention to the subject. However, studies focusing on a geography that transforms and changes with the effect of dynamic parameters in the temporal process are limited. Today, by superimposing these dynamic processes, perceiving and interpreting a complex problem above human intelligence through machine learning based on algorithms is possible. Evaluating these opportunities in spatial analysis

based on probabilities is significant for decision authorities (Feizizadeh et al. 2021; Islam et al. 2021).

This study examines the comprehensive planning approach currently being implemented in Turkish legislation from the perspective of resilience to climate change. While making spatial decisions to produce cities resistant to climate change, forecast maps are produced according to climate change scenarios based on the need for people to feel bioclimatically comfortable in changing climatic conditions. The Western Mediterranean basin, one of the country's southernmost regions, was chosen as the research material.

The research questions that will enable to focus on the main objectives of this study have been determined as follows:

RQ₁: How will the climate crisis affect high-risk geographies in terms of bioclimatic comfort in hot climate regions?

RQ₂: What are the guiding ideas that spatial models of climate risk provide for planning at the scale of a fragile watershed?

Data and methods

Conceptual framework

Urban resilience is often defined as the readiness of urban systems to survive the dangers of sudden emergencies (Dastjerdi et al. 2021; Huang et al. 2021; Wardekker 2021). The fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC 2014) defines the concept of resilience as “sustaining the capacity of social, economic and environmental systems to cope with a dangerous event or trend or disturbance while maintaining their essential functions, identities, and structures,” while at the same time adapting is defined as “the capacity to respond or rearrange appropriately.” Shocks may occur unexpectedly, such as terrorism, disasters, economic depressions, and significant accidents (Botha et al. 2021; Chen and Chang 2021). In addition, a danger that can affect the world is the risk brought by climate change. According to Simpson et al. (2021), we live in a highly networked world where, like the risks themselves, multiple drivers of climate change risk interact. The climate crisis is a threat that urban areas, where more than half of the world's population lives, must gain resilience. Urban and regional economies need to be prepared for the devastation and costs of the climate crisis.

The concept of urban resilience is examined in 4 groups: ecological resilience, resilience to hazards and disaster risks, economic resilience, and resilience produced through governance and institutions. Climate change has recently been recognized as a new source of risk for the financial system (Battiston et al. 2021). It is emphasized that green policies

Fig. 1 Flowchart of the study

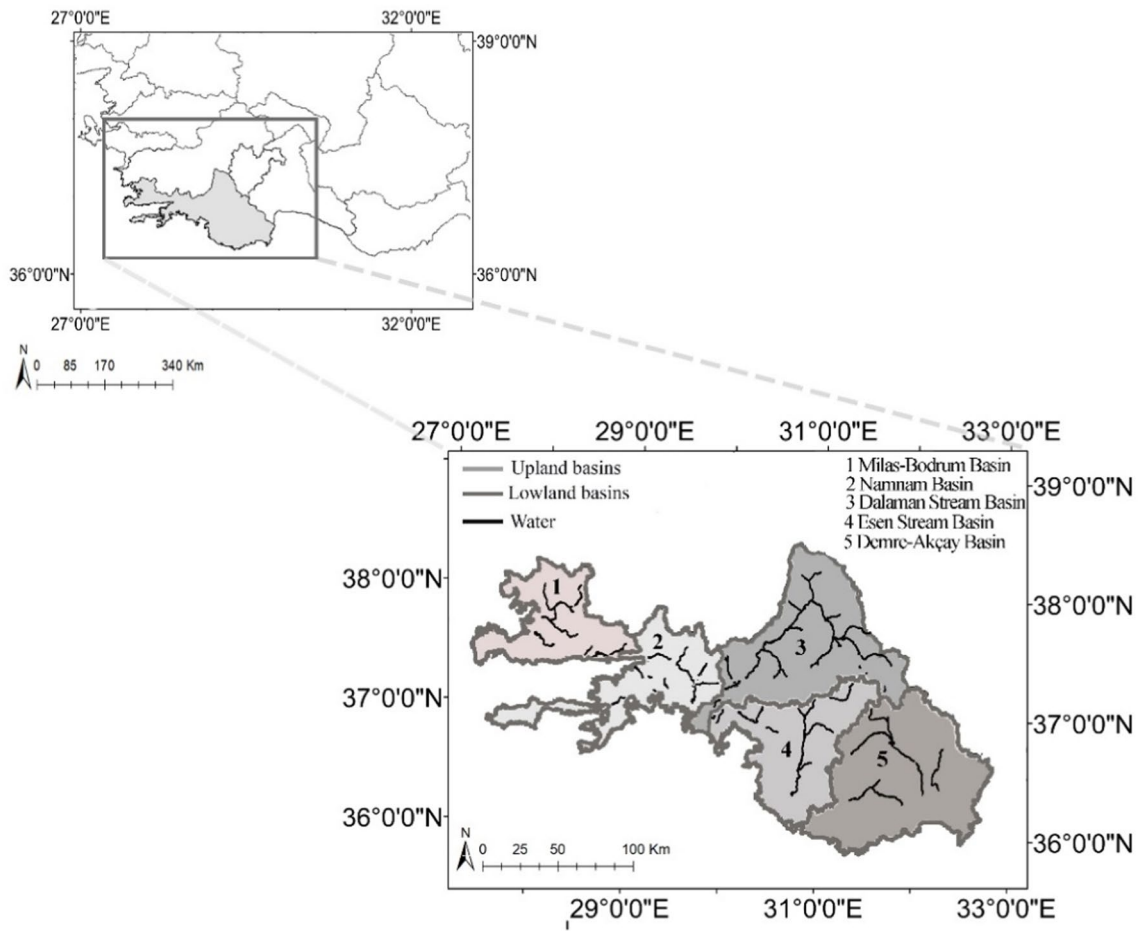
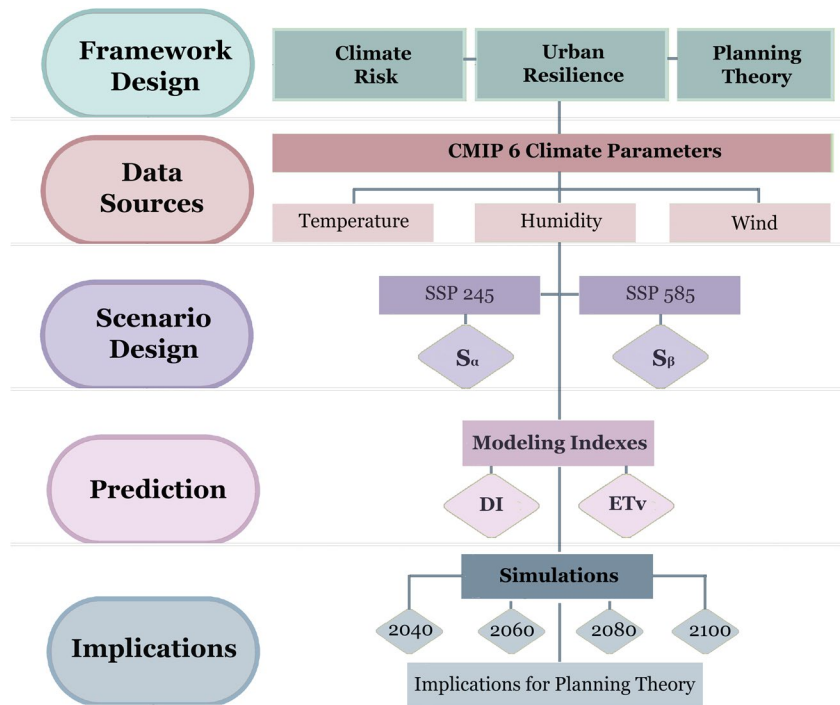


Fig. 2 Map of the study area

are urgently needed against these developments that shake both the real economy and the financial system (Lamperti et al. 2021). On the other hand, Kim and Lim (2016) focus on sociopolitical, ecological, and engineering resilience in their research on resilience and adaptation to climate change. However, in today's cities, where urban complexity has intensified over time, it will be necessary to diversify resilience levels in the context of planning.

Modeling methodology

The modeling process consists of five primary stages. After the research design was made depending on the theoretical foundations, the parameters used in the modeling were defined, and the data set related to the research area was created. In light of these data, the changes according to the scenarios were determined using the Discomfort Index (DI) and Effective Temperature Taking Wind Velocity (ET_v) indexes to model the change in bioclimatic comfort zones. The simulations obtained after the future predictions were made were evaluated in terms of planning theory (Fig. 1).

Materials of modeling

The research material is from the Western Mediterranean basin on the Mediterranean coast, located southwest of the country. The research area covers a very rich geography in terms of land cover, covering five sub-basins. The Mediterranean, where temperatures increase 20% faster than the global average, is stated as the fastest-warming and saltiest sea on our planet. The new report of WWF (World Wildlife Fund) and the "Effects of Climate Change in the Mediterranean" reveals this increase's concrete and grave consequences across the basin. By 2100, it is estimated that the sea level will rise by more than 1 m, and one-third of the region's population will be affected. The Mediterranean basin, the area where the effects of climate change will be experienced most severely, is currently considered vulnerable to desertification.

It is thought that these developments, which are very difficult to control in the region according to climate change scenarios, will result in global human migrations. The area represents a highly fragile region with changes such as less precipitation compared to the past, increased floods and overflows due to shorter and more severe precipitation, heat waves, drought, and forest fires accordingly. For example, forest fires are seen as one of the most severe problems affecting the countries in the Mediterranean climate region, and the importance of the issue is reflected in fire risk maps (Teodoro and Duarte 2013). Despite these risks, the Western Mediterranean basin is in a position that includes the most attractive touristic places in the country, such as Bodrum, Marmaris, Dalaman, and Fethiye (Fig. 2).

Data preparation and scenario design

Global data sets within the scope of the Combined Model Intercomparison Project Phase 6 (CMIP6), which is being prepared by the World Climate Research Program (WCRP), are updated by the IPCC in light of new developments and used together with climate scenarios. The climate data was obtained from the measurements made between 2000 and 2020 by the 24 meteorology stations. The data obtained were obtained from the General Directorate of Meteorology. Future bioclimatic comfort maps were obtained by applying bioclimatic comfort index formulas to the maps created by this method. Data on high-resolution climate projections were obtained from the National Lawrence Livermore Department of Energy (Lawrence Livermore National Laboratory) data system. The scenarios of the CNRM-CM6-1 climate change model were selected. SSPs 245 and SSPs 585 scenarios were downloaded in NetCDF file format. The "Inverse Distance Weighted (IDW)" analysis was used to map the climate data using ArcMap 10.8. The basic equation of the Inverse Distance Weighted (IDW) is as follows (Eq. (1)):

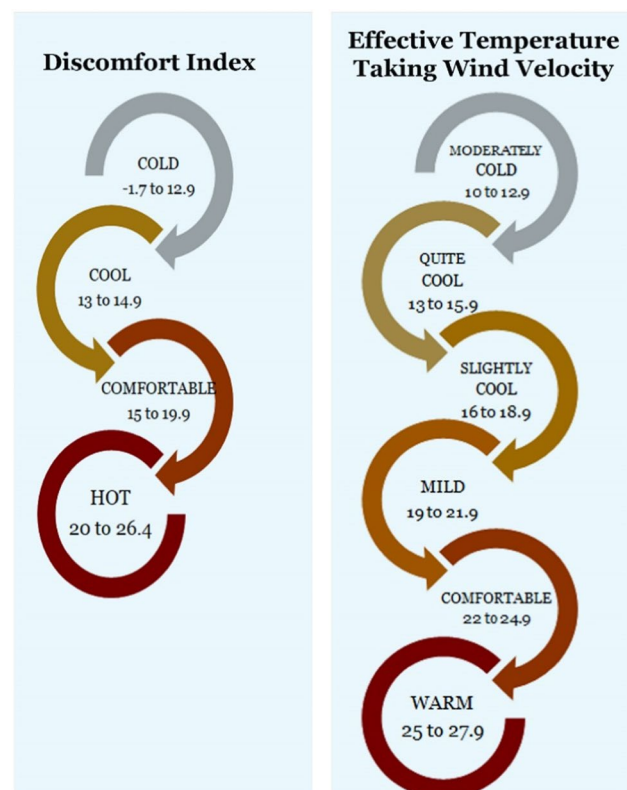


Fig. 3 Meanings of indexes according to values

$$z(x_0) = \frac{\sum_{i=1}^n z(x_i) \cdot d_{i0}^{-r}}{\sum_{i=1}^n d_{i0}^{-r}} \tag{1}$$

The location X_0 where the estimations are made is a function of neighbor measurements $n [z(X_{0i})$ and $i=1,2,\dots,n]$; r is the exponent determining the assigned range of each of the observations, and d is the distance separating the observation location X_i from the prediction location X_0 . The larger the exponent, the less the assigned weight of observations far from the forecast location. An increase in the exponent means that the estimates are very similar to the closest observations. The mathematical formulas are as described above, and climate maps are produced from calculations made using the ArcGIS software program. Then, bioclimatic comfort maps were obtained by applying two different bioclimatic comfort index formulas to the climate maps of each scenario.

Indexes for classification of bioclimatic comfort zones

There are many evaluation indices developed for the classification of bioclimatic comfort zones. Some of them are Thom’s discomfort index (DI) (1959), temperature humidity index (THI) (Emmanuel 2005), relative strain index (RSI) (Lee 1965), standard effective temperature index (SET) (Gagge 1971), physiologically equivalent temperature (PET) (Mayer and Höpfe 1987), and ET_v (Suping et al. 1992). The first of the indexes applied in the study is DI, and it is formulated as follows (Eq. (2)):

$$DI = T - (0.55 - 0.0055 \times RH) \times (T - 14.5) \tag{2}$$

where T is the monthly average temperature ($^{\circ}\text{C}$) and RH is the relative humidity (%).

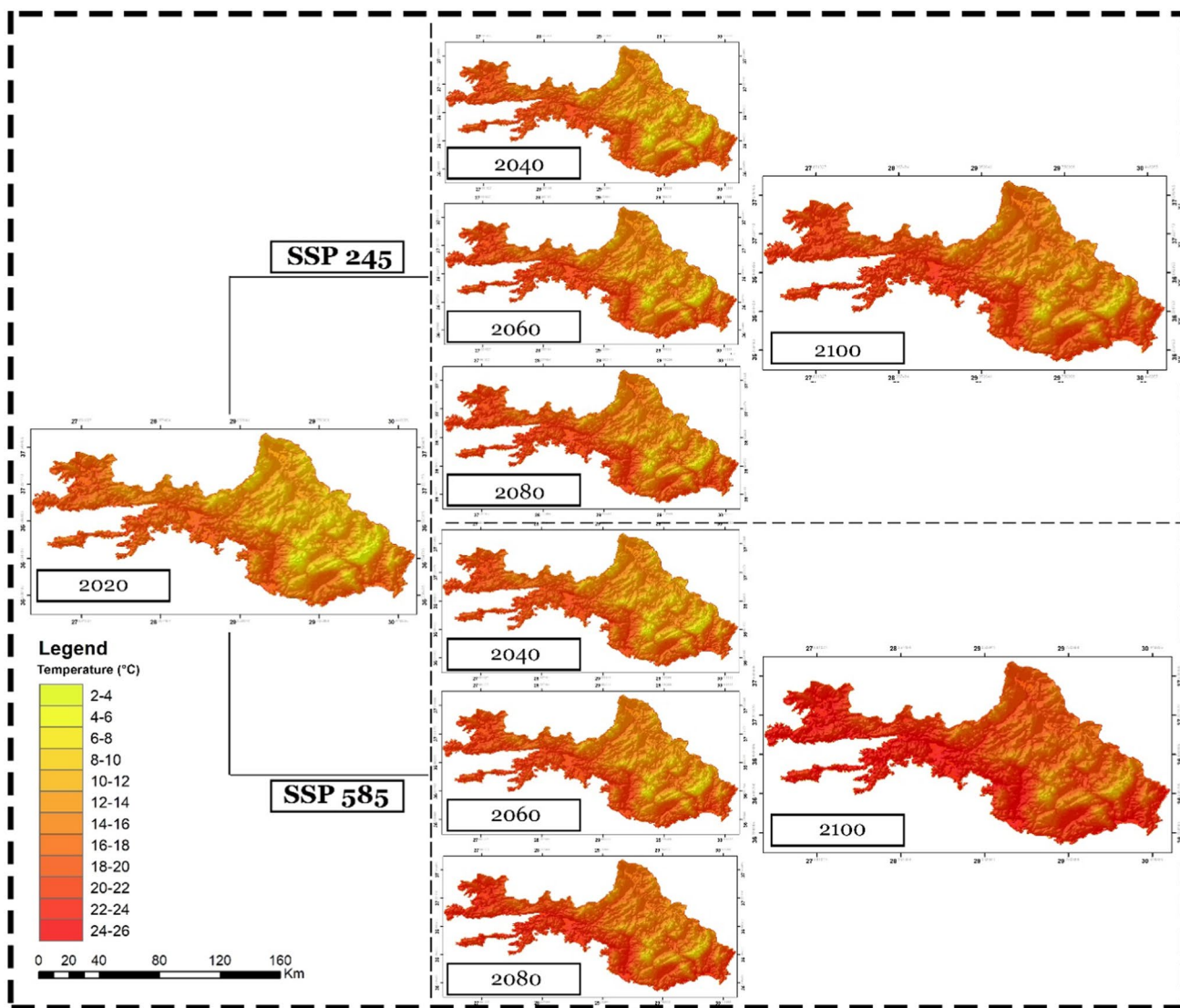


Fig. 4 Risk of temperature rise from climate change

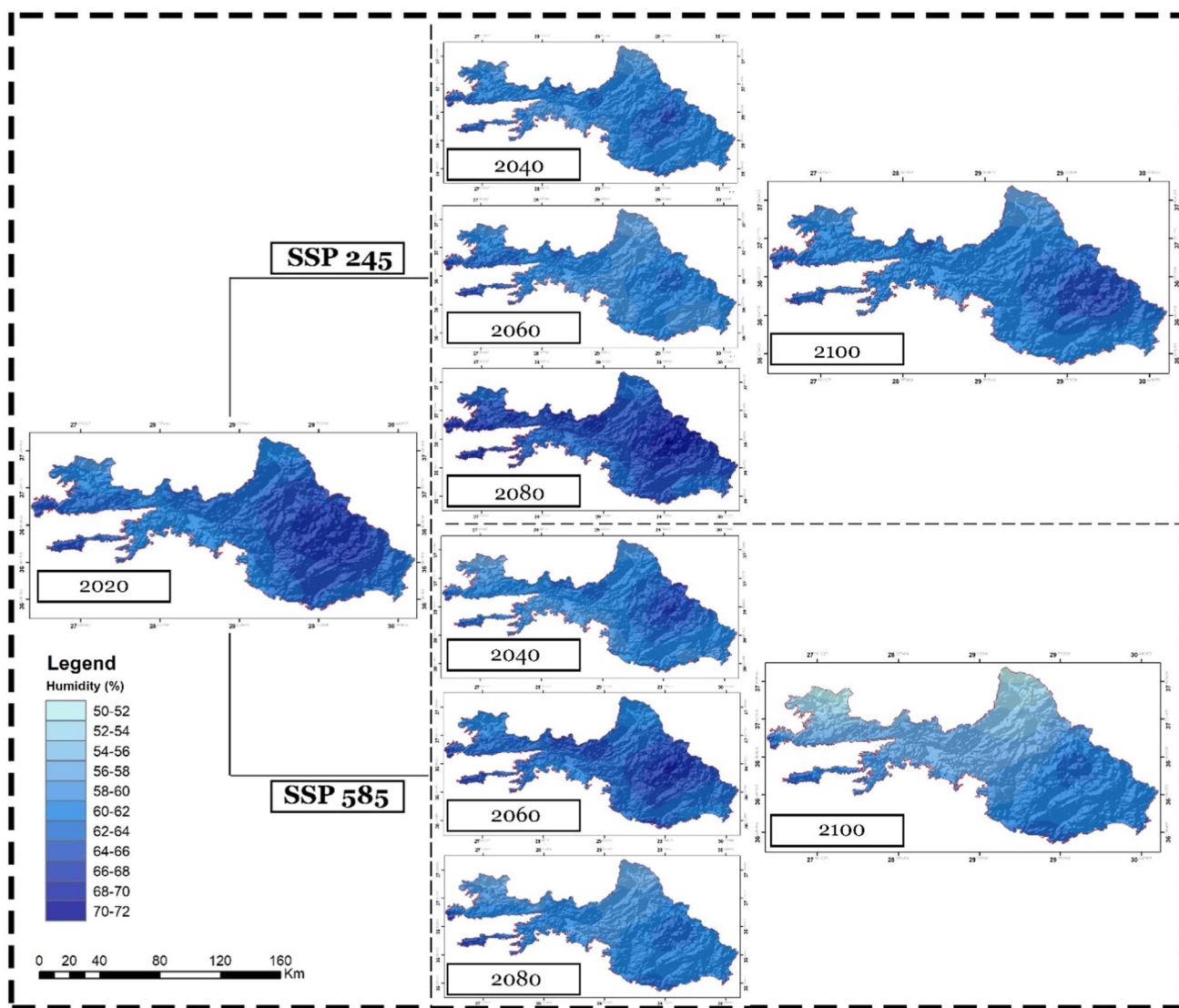


Fig. 5 Humidity change risk of climate change

According to the intervals of the index values, the feeling of thermal comfort is interpreted according to specific intervals. This classification ranges from extremely cold to extremely hot. DI has ten primary classifications. Three are warmer than comfortable, and six are cold in Fig. 3.

The second index used in the study is ET_v . According to this index, comfort zones are based on the formula in Eq. (3):

$$ET_v = 37 - (37 - T) / [0.68 - 0.0014RH + 1 / (1.76 + 1.4v^{0.75})] - 0.29T(1 - RH/100) \tag{3}$$

where T is the dry bulb temperature ($^{\circ}C$), RH is the relative humidity (%), and v is the wind speed (m/s).

ET_v comfort classification includes thermal sensation and degree of physiological stress interpretations. There are thermal sensation values in the very cold-very hot range. In terms of physiological stress, it has extreme cold stress and thermoregulatory failure classifications.

The changes in the predicted climate parameters according to the SSP 245 and SSP 585 scenarios of the CNRM-CM6-1 model and the comfort intervals obtained in the ID and ET_v indexes depending on the scenarios were modeled for the basin. The values obtained for the determined indexes were interpreted.

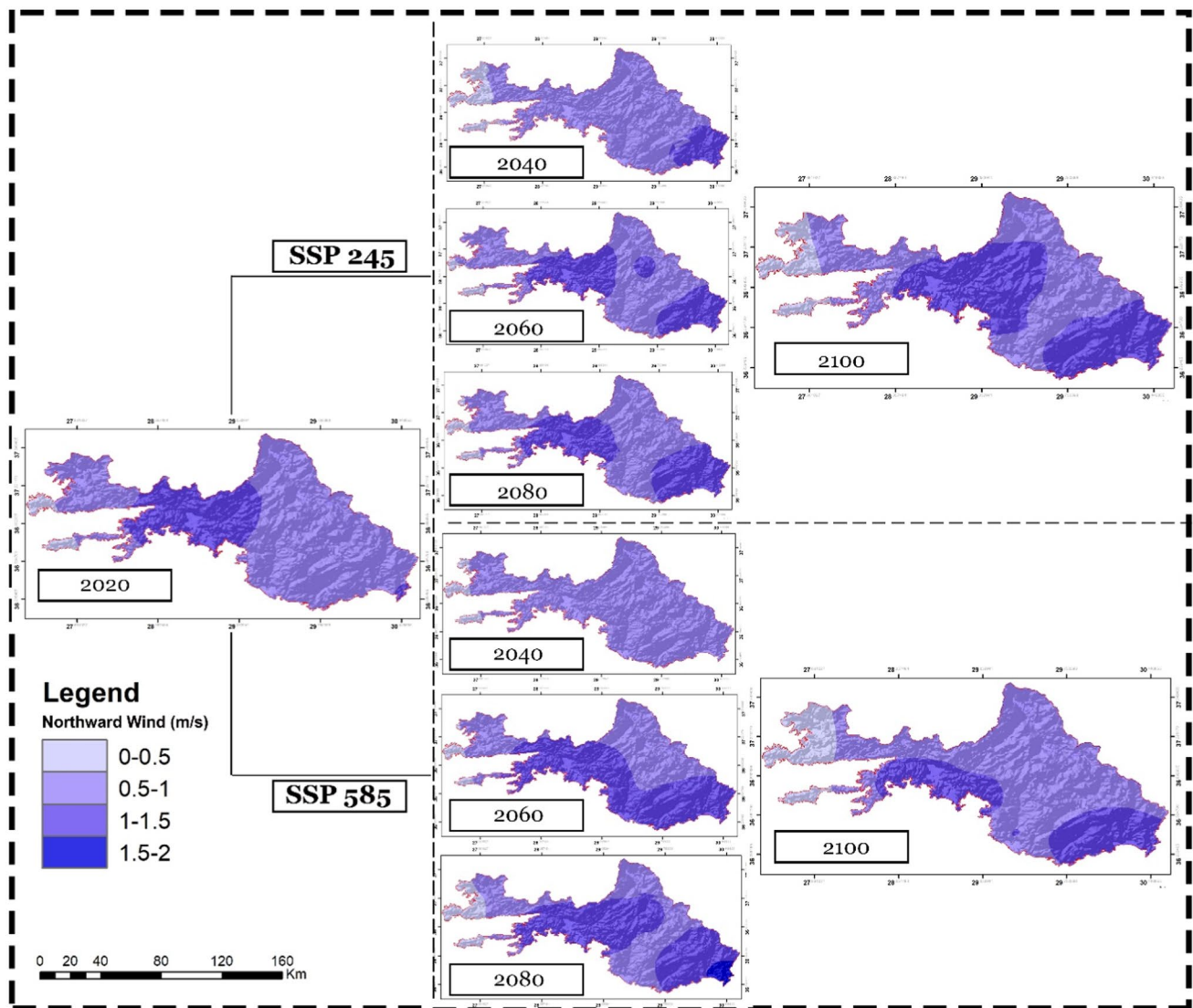


Fig. 6 Wind change risk of climate change

Results and discussion

Changes in climate parameters

The change in the spatial distribution of temperature in the forecasts produced depending on the determined scenarios is quite striking. Today, the range between 10 and 20 °C constitutes the general area. According to the most significant values, 18% are in the range of 10–12 °C, 19% in the range of 12–14 °C, 13% in the range of 14–16 °C, and 17% in the range of 18–20 °C. According to SSP 245, areas between 18 and 20 °C will reach 26% in 2040, and areas above 20 °C will have an area of 6%. According to this scenario, 20–22 °C surfaces will increase to 28% in 2100, and areas between 22 and 24 °C, which do not exist today, will constitute 3% of the basin (Fig. 4).

The fluctuations in humidity values are striking in the maps produced according to SSP 245 and SSP 585. Today, 37% of the area is at a 62–64% humidity level, and these values are dominant in the area. According to SSP 245, in 2100, 58% of the area will be comprised of 60–62% areas. According to SSP 585, areas in this range will account for 31%, while 50–52% of areas that do not exist today will account for 3%, 52–54% areas 7%, 54–56% areas 11%, and 56–58% areas 28% (Fig. 5).

The irregularity in the spatiotemporal distribution of wind speed is quite evident. Today, 75% of the area receives winds at a speed of 0.5–1 m/s⁻¹. Areas with 1–1.5 wind speeds cover an area of 22%. According to SSP 585, while there is no area in the range of 1–1.5 in 2040, it is predicted that 56% of the area will be exposed to this wind in 2060. This wind behavior is predicted as a harbinger of extreme events (Fig. 6).

Predictions via DI and ETv indexes

The DI classification categorized the basin as cold, cool, comfortable, and hot. Today, 43% of the basin is comfortable, 19% is cool, 38% is cold, and there is no hot area. According to SSP 245, by 2100, 9% of the area will be cold, 19% will be cool, and 59% will be comfortable. In addition, 13% of the surface area will turn into hot areas. SSP585 states this rate is 41%, and cold and cool areas will decrease to 7%. The DI index predicts all touristic coastal areas in the basin as hot (Fig. 7).

While DI bioclimatic areas examined the basin in four classes, the ETv index determined ten ranges. Today, 1% of the area is cold, 12% is moderately cold, 37% is quite cool, and 35% is slightly cool. According to SSP 245, the

area is dominated by slightly cool areas (38%). Also, warm (2%) and quite hot (1%) users will start to appear. Mild (43%) and comfortable areas (26) will occupy a large area, according to SSP 585. It will show the same feature as SSP 245, while quite hot areas will create an area of 1%, while warm areas will increase to 7%. The ETv index predicts Bodrum and Marmaris settlements, which have high tourism potential in the basin, as warm and quite hot (Fig. 8).

Implications for planning theory

Climate change is uncertain, unpredictable, and destructive; impactful transformation demands accepting the uncertainty and its unpredictability (Nightingale et al. 2022). The Paris Agreement defines targets to limit the increase in global

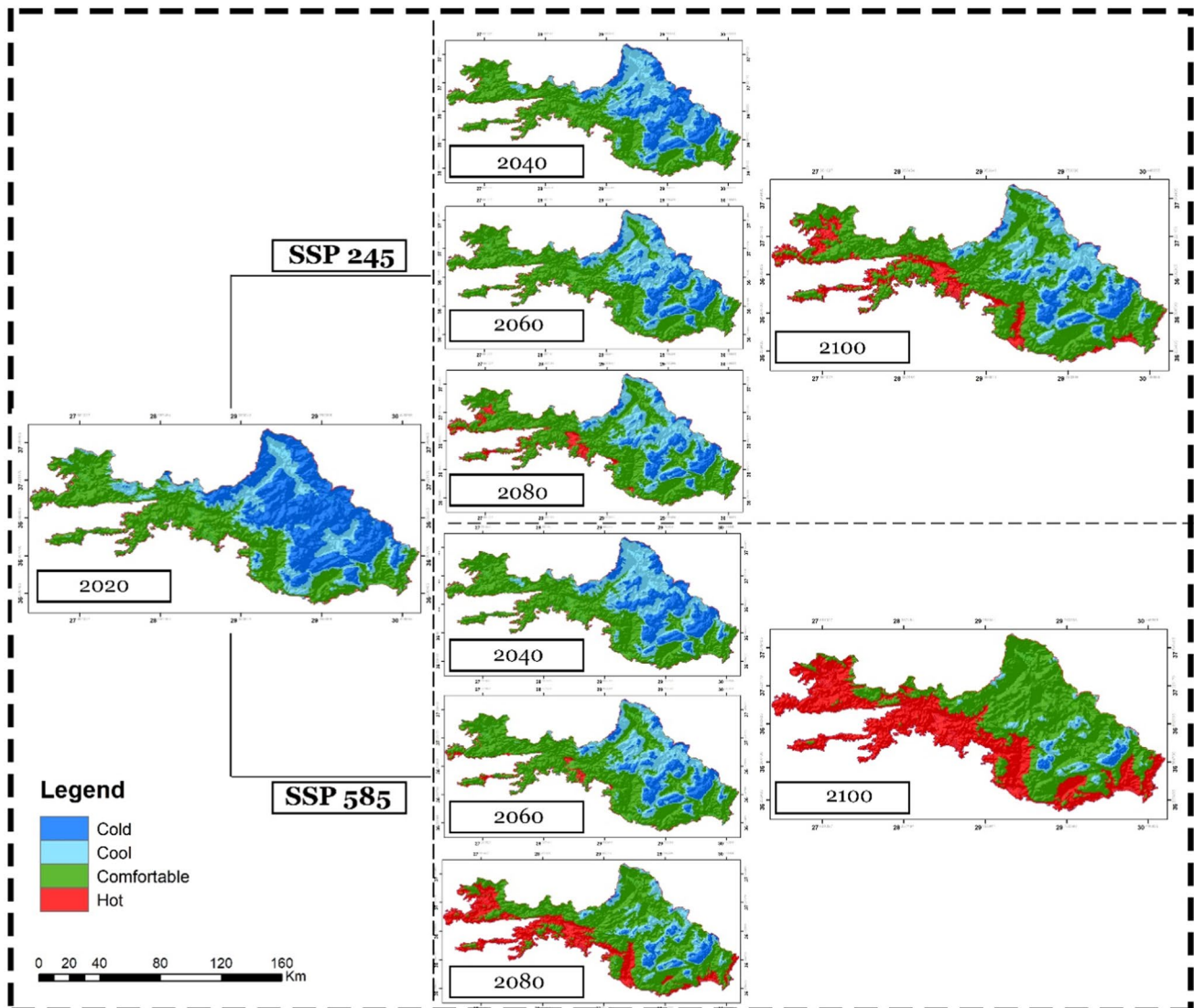


Fig. 7 Simulations of bioclimatic comfort zones concerning DI

average temperature to 1.5 °C (UNFCCC 2022). The increase in temperature values in terms of time indicates drought in specific geographies (Dikici 2022; Kamruzzaman et al. 2022; Tran et al. 2023). However, the fluctuating course of humidity and wind parameters gives signals of unexpected events (Li et al. 2022; Qiao et al. 2022). The cities of the future cannot adhere to the theories produced in the cities of the twentieth century (Nieuwenhuijsen 2021). More severe changes and transformations are inevitable in today's cities, where endless stakeholders and representatives interact and create unexpected situations (Krzemińska et al. 2022). Informatics, software, and mathematics-based models, which we have started to use widely, allow us to understand relational behaviors based on scenarios and produce predictions (Badwi et al. 2022). The models reveal that the settlements suitable for bioclimatic

conditions today and that receive intense migration will need cooling systems in the future and will threaten many health problems, especially circulatory and respiratory systems, in risky groups in specific periods (Bedair et al. 2023). With the heat island effect, urban areas have higher temperatures than rural areas, increasing the need for intervention (Wang et al. 2019). Future conditions refer to the energy required to bring the environment's temperature to comfortable ranges (Li et al. 2019). Therefore, depending on the increase in temperature due to climate change, there will be oscillations that will trigger the change again. The way to prevent this is to consider suitable areas in terms of comfort while choosing the location of urban developments and investments (Isinkaralar 2023).

Three main breaking points form the basis of cities. The first of these is the settlement of societies. As we understand

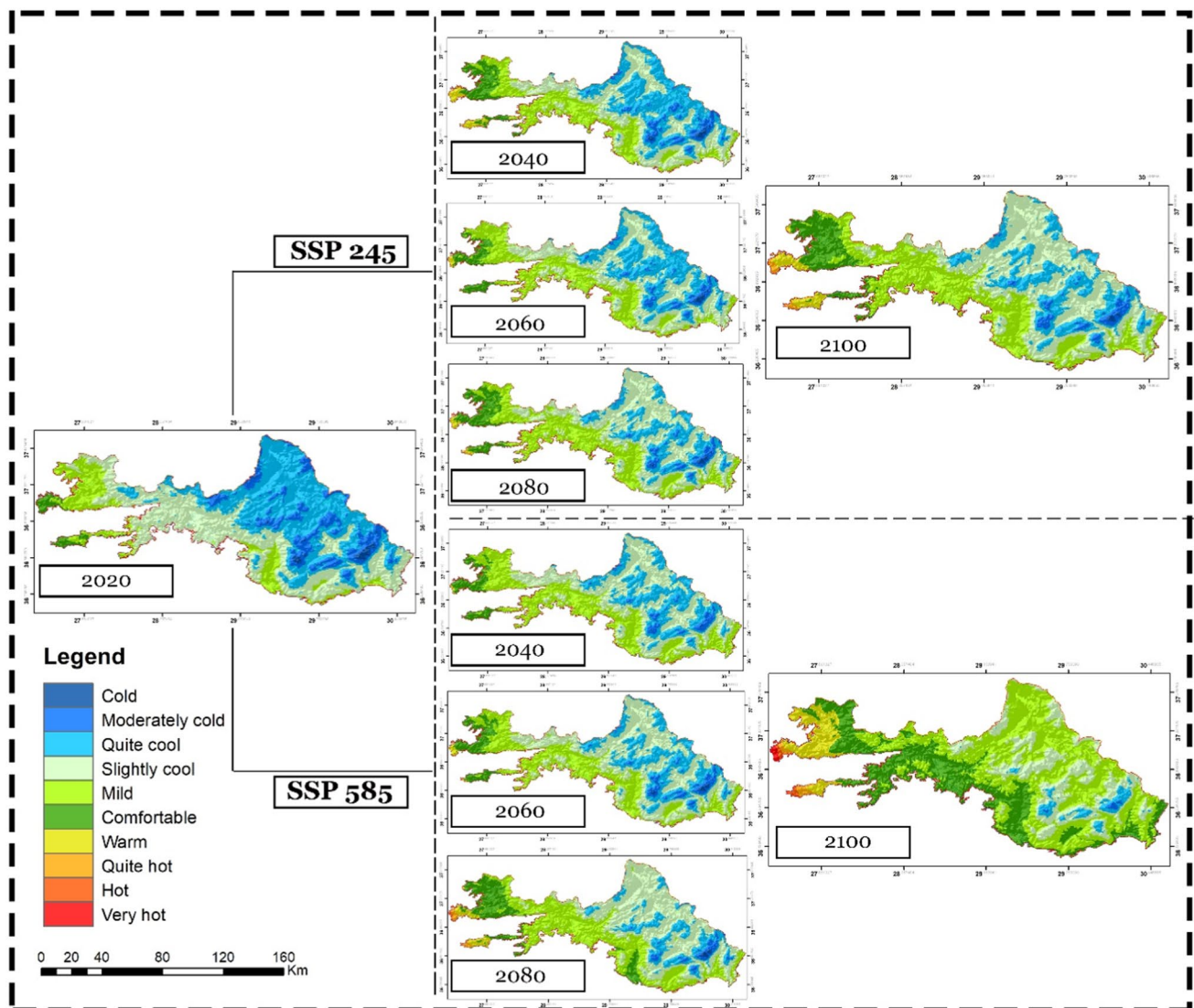


Fig. 8 Simulations of bioclimatic comfort zones depending on the ETv index

it now, cities began to form after the industrial revolution (Mobaraki and Oktay Vehbi 2022; Zhang et al. 2022). On the other hand, the technological and information revolution brought by our age initiates a period in which changes are/will be experienced more rapidly. Therefore, criteria such as transportation, market, and raw materials, which are defined by traditional site selection theories and constitute the basis of planning, are differentiated in today's cities with the decrease in spatial dependency with developments such as e-commerce (Liu et al. 2022; Isinkaralar and Varol 2023). Reducing the population density in urban centers is possible with remote working conditions in an order in which the rural–urban distinction is eliminated. It is impossible to ignore urban social life and publicity. However, it is a fundamental deficiency that comfort areas are not included in the analysis of suitability for settlement in buildings where urban growth continues.

Actions on urban activities responsible for anthropic activity and greenhouse gases are urgent (Allam et al. 2022; Marino et al. 2023). At the forefront of these is the development of sustainable transportation infrastructure and systems free from fossil fuels. Solutions produced individually by integrating alternative energy sources into sustainable building technologies can provide a reduction in the whole. To

reduce the urban heat island effect, it can be expanded with blue-green areas with high albedo values from the upper scale to the local level. In this context, the urban green space setup should choose a place with comprehensive analytical analysis. A network structure is needed for sustainable interaction between the physical structure, society, and decision authorities. A resilient city to climate risk must be based on a resilient social structure (Yabe et al. 2022). International funding support should be provided to combat devastating dangers, especially in low- and middle-income countries. Investment and employment management in areas prone to risk should be directed to low-risk areas. Mixed-use planning, which offers diversity and addresses different lifestyles by contributing to the development of a sense of community and belonging, can be evaluated within the scope of disaster management. Climate risks are summarized in Table 1.

Conclusions and research gaps

Models produced with a holistic approach at the basin scale emphasize the future spatial threats the climate crisis will bring. Planning for adaptation to climate change should strengthen the link between science and society

Table 1 Climate risk in its most fundamental dimensions

Managerial and ownership dimension	Climate risk may require people to migrate from their settled areas. In this respect, there is a need for intervention forms that will reduce the exposure rate. However, while making decisions, the administrative jurisdictions overlap. The country has its chiefs at the provincial borders. However, the management of the basin borders and regional borders is carried out centrally. Therefore, there is a need for an official channel in the basins in terms of coordination. Possible human movements can create a discussion area on public/private property and in new development areas
Health and productivity dimension	The increase in temperature values is pronounced. Although there is a fluctuating course in humidity values, a climate prone to drought and up-and-down movements in the wind indicator can trigger physical and mental diseases. While exposure affects the daily activities of individuals and households, failure to take necessary precautions requires investigation of physiological and psychological factors. The optimum level of bioclimatic parameters is a basic need for individuals to feel energetic and healthy and not experience thermal stress. In terms of working efficiency and happiness, people try to bring them to appropriate values. However, the dominance of external factors is a possible threat in terms of health and productivity. Deprived of opportunities and with low entitlements, households may need operational and economic support. Since the vulnerability of risky or disadvantaged groups in terms of health is high, resilience can only be achieved by reducing the exposure level
Cost and financial dimension	The provision of public services, especially the necessary equipment support in the event of a disaster, and the instruments required to reconstruct the areas are financially essential threats. Natural disasters are sensitive to political and economic approaches. Therefore, the economic vulnerability of the poor citizens of underdeveloped countries is high in the process
Density dimension	In terms of density, the element that should be dealt with as a priority is human and living life. Planning is a fundamental tool for reducing the intensity of triggering factors (vehicle density, building density, etc.) in the context of reducing the risk of climate change. The spatial location selection of the population affected by the risk should be discussed comprehensively
Quality dimension	The quality dimension should be evaluated in terms of spatiality and quality of life. While the expected risks pose a threat to the quality of the space, the quality of urban life is affected by bioclimatic comfort. Fair and equitable city planning protects society from exposure to risks and harm by setting goals from the abovementioned essential perspectives. However, since urban planning is a multi-stakeholder discipline with representatives at different levels, teamwork with the principles of reducing vulnerability in the climate crisis may be appropriate

and deal with risks by analyzing the temporal processes of the dynamics that create complexity. However, it is not an appropriate approach to accept the process and defend against threats without producing strategies for mitigation. The planning theory must evolve according to current conditions as the world order, cities, and lifestyles change. Critical decision-makers and urban planners manage natural disasters in terms of climate risk and need to be equipped to restore the city or region to its former balance. The necessity of a flexible paradigm comes to the fore in the comprehensive long-term plans currently being implemented.

The data for this research consists of station sources. More research needs to be done with alternative data generation methods. In addition, local-specific evaluations can be developed by enriching the determined indexes with local data. Indeed, this research is limited to selected methods. In Türkiye, basin-scale studies are limited, and administrative and basin boundaries do not coincide in administrative decisions. New determinations can be reached by evaluating the produced models with other basin-based data in different areas.

Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interest The authors declare no competing interests.

References

- Allam Z, Bibri SE, Chabaud D, Moreno C (2022) The ‘15-minute city’ concept can shape a net-zero urban future. *Humanities and Social Sciences Communications* 9(1):1–5. <https://doi.org/10.1057/s41599-022-01145-0>
- Badwi IM, Ellaithy HM, Youssef HE (2022) 3D-GIS parametric modelling for virtual urban simulation using CityEngine. *Ann GIS* 28(3):325–341. <https://doi.org/10.1080/19475683.2022.2037019>
- Battiston S, Dafermos Y, Monasterolo I (2021) Climate risks and financial stability. *J Fin Stab* 54:100867. <https://doi.org/10.1016/j.jfs.2021.100867>
- Bedair H, Alghariani MS, Omar E, Anibaba QA, Remon M, Bornman C et al (2023) Global warming status in the African continent: sources, challenges, policies, and future direction. *Int J Environ Res* 17(3):45. <https://doi.org/10.1007/s41742-023-00534-w>
- Berke P, Kates J, Malecha M, Masterson J, Shea P, Yu S (2021) Using a resilience scorecard to improve local planning for vulnerability to hazards and climate change: an application in two cities. *Cities* 119:103408. <https://doi.org/10.1016/j.cities.2021.103408>
- Botha F, de New JP, de New SC, Ribar DC, Salamanca N (2021) Implications of COVID-19 labour market shocks for inequality in financial wellbeing. *J Popul Econ* 34(2):655–689. <https://doi.org/10.1007/s00148-020-00821-2>
- Browning MH, Rigolon A, McAnirlin O (2022) Where greenspace matters most: a systematic review of urbanicity, greenspace, and physical health. *Landscape Urban Planning* 217:104233. <https://doi.org/10.1016/j.landurbplan.2021.104233>
- CastánBroto V, Robin E (2021) Climate urbanism as critical urban theory. *Urban Geogr* 42(6):715–720. <https://doi.org/10.1080/02723638.2020.1850617>
- Chen X, Chang CP (2021) The shocks of natural hazards on financial systems. *Nat Hazards* 105(3):2327–2359. <https://doi.org/10.1007/s11069-020-04402-0>
- Cifuentes-Faura J (2022) European Union policies and their role in combating climate change over the years. *Air Qual Atmos Health* 15(8):1333–1340. <https://doi.org/10.1007/s11869-022-01156-5>
- Dastjerdi MS, Lak A, Ghaffari A, Sharifi A (2021) A conceptual framework for resilient place assessment based on spatial resilience approach: an integrative review. *Urban Climate* 36:100794. <https://doi.org/10.1016/j.uclim.2021.100794>
- Dikici M (2022) Drought analysis for the Seyhan Basin with vegetation indices and comparison with meteorological different indices. *Sustainability* 14(8):4464. <https://doi.org/10.3390/su14084464>
- Dogan S, Kilicoglu C, Akinci H, Sevik H, Cetin M (2022) Determining the suitable settlement areas in Alanya with GIS-based site selection analyses. *Environ Sci Pollut Res* 30(11):29180–29189. <https://doi.org/10.1007/s11356-022-24246-4>
- Emmanuel R (2005) Thermal comfort implications of urbanization in a warm-humid city: the Colombo Metropolitan Region (CMR). *Sri Lanka Build Environ* 40(12):1591–1601. <https://doi.org/10.1016/j.buildenv.2004.12.004>
- Feizizadeh B, Omarzadeh D, Kazemi Garajeh M, Lakes T, Blaschke T (2021) Machine learning data-driven approaches for land use/cover mapping and trend analysis using Google Earth Engine. *J Environ Plan Manag* 66(3):665–697. <https://doi.org/10.1080/09640568.2021.2001317>
- IPCC (2014) Climate Change 2014: impacts, adaptation, and vulnerability. Working Group II contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Available at: <http://www.ipcc.ch/>. Accessed Aug 2022
- Gagge AP (1971) An effective temperature scale based on a simple model of human physiological regulatory response. *Ashrae Trans* 77:247–262
- Giri M, Bista G, Singh PK, Pandey R (2021) Climate change vulnerability assessment of urban informal settlers in Nepal, a least developed country. *J Clean Prod* 307:127213. <https://doi.org/10.1016/j.jclepro.2021.127213>
- Grigorieva EA, Livenets AS (2022) Risks to the health of Russian population from floods and droughts in 2010–2020: a scoping review. *Climate* 10(3):37. <https://doi.org/10.3390/cli10030037>
- Hazra S, Ghosh A, Ghosh S, Pal I, Ghosh T (2022) Assessing coastal vulnerability and governance in Mahanadi Delta, Odisha India. *Prog Dis Sci* 14:100223. <https://doi.org/10.1016/j.pdisas.2022.100223>
- He G, Bao K, Wang W, Zhu Y, Li S, Jin L (2021) Assessment of ecological vulnerability of resource-based cities based on entropy-set pair analysis. *Environ Technol* 42(12):1874–1884. <https://doi.org/10.1080/09593330.2019.1683611>

- He W, Zhang L, Yuan C (2022) Future air temperature projection in high-density tropical cities based on global climate change and urbanization—a study in Singapore. *Urban Climate* 42:101115. <https://doi.org/10.1016/j.uclim.2022.101115>
- Huang G, Li D, Zhu X, Zhu J (2021) Influencing factors and their influencing mechanisms on urban resilience in China. *Sustainable Cities and Society*, 74, 103210. <https://doi.org/10.1016/j.scs.2021.103210>
- Isinkaralar K (2022) Temporal variability of trace metal evidence in *Cupressus arizonica*, *Platanus orientalis*, and *Robinia pseudoacacia* as pollution-resistant species at an industrial site. *Water Air Soil Pollut* 233(7):250. <https://doi.org/10.1007/s11270-022-05743-1>
- Isinkaralar O (2023) Bioclimatic comfort in urban planning and modeling spatial change during 2020–2100 according to climate change scenarios in Kocaeli, Türkiye. *Int J Environ Sci Technol* 20(7):7775–7786. <https://doi.org/10.1007/s13762-023-04992-9>
- Isinkaralar O, Varol C (2023) A cellular automata-based approach for spatio-temporal modeling of the city center as a complex system: the case of Kastamonu, Türkiye. *Cities* 132:104073. <https://doi.org/10.1016/j.cities.2022.104073>
- Isinkaralar O, Varol C, Yilmaz D (2022) Digital mapping and predicting the urban growth: integrating scenarios into cellular automata—Markov chain modeling. *Appl Geo* 14(4):695–705. <https://doi.org/10.1007/s12518-022-00464-w>
- Islam MD, Islam KS, Ahasan R, Mia MR, Haque ME (2021) A data-driven machine learning-based approach for urban land cover change modeling: a case of Khulna City Corporation area. *Remote Sens Appl: Soc Environ* 24:100634. <https://doi.org/10.1016/j.rsase.2021.100634>
- Ivaldi S, Scaratti G, Fregnan E (2022) Dwelling within the fourth industrial revolution: organizational learning for new competences, processes and work cultures. *J Work Learn* 34(1):1–26. <https://doi.org/10.1108/JWL-07-2020-0127>
- Jasour ZY, Reilly AC, Tonn GL, Ferreira CM (2022) Roadway flooding as a bellwether for household retreat in rural, coastal regions vulnerable to sea-level rise. *Climate Risk Management* 36:100425. <https://doi.org/10.1016/j.crm.2022.100425>
- Kamruzzaman M, Almazroui M, Salam MA, Mondol MAH, Rahman MM, Deb L, Kundu PM, Zaman MAU, Islam ARMT (2022) Spatiotemporal drought analysis in Bangladesh using the standardized precipitation index (SPI) and standardized precipitation evapotranspiration index (SPEI). *Sci Rep* 12(1):20694. <https://doi.org/10.1038/s41598-022-24146-0>
- Kang L, Yang Z, Dang Y, Zhang W, Liu C (2022) Can tourism development make cities more livable? Investigating 40 cities in China. *Int J Environ Res Public Health* 19(1):472. <https://doi.org/10.3390/ijerph19010472>
- Kim D, Lim U (2016) Urban resilience in climate change adaptation: a conceptual framework. *Sustainability* 8(4):405. <https://doi.org/10.3390/su8040405>
- Krzemińska A, Zaręba A, Modelska M, Adyńkiewicz-Piragas M, Kozik R (2022) City profile: city profile: Wałbrzych—the postindustrial ‘citymorphosis’ of a former coal mine city in Poland. *Cities* 129:103933. <https://doi.org/10.1016/j.cities.2022.103933>
- Kumar K, Pande BP (2023) Air pollution prediction with machine learning: a case study of Indian cities. *Int J Environ Sci Technol* 20(5):5333–5348. <https://doi.org/10.1007/s13762-022-04241-5>
- Lamperti F, Bosetti V, Roventini A, Tavoni M, Treibich T (2021) Three green financial policies to address climate risks. *J Fin Stab* 54:100875. <https://doi.org/10.1016/j.jfs.2021.100875>
- Lee DHK (1965) Climatic stress indices for domestic animals. *Int J Biometeorol* 9(1):29–35. <https://doi.org/10.1007/BF02187306>
- Li X, Zhou Y, Yu S, Jia G, Li H, Li W (2019) Urban heat island impacts on building energy consumption: a review of approaches and findings. *Energy* 174:407–419. <https://doi.org/10.1016/j.energy.2019.02.183>
- Li XY, Guan YH, Law SS, Zhao W (2022) Monitoring abnormal vibration and structural health conditions of an in-service structure from its SHM data. *J Sound Vib* 537:117185. <https://doi.org/10.1016/j.jsv.2022.117185>
- Liu X, Tong D, Huang J, Zheng W, Kong M, Zhou G (2022) What matters in the e-commerce era? Modelling and mapping shop rents in Guangzhou China. *Land Use Policy* 123:106430. <https://doi.org/10.1016/j.landusepol.2022.106430>
- Mansuroğlu S, Dağ V, KalaycıÖnaç A (2021) Attitudes of people toward climate change regarding the bioclimatic comfort level in tourism cities; evidence from Antalya, Türkiye. *Türkiye Environ Mon Assess* 193(7):1–16. <https://doi.org/10.1007/s10661-021-09205-9>
- Marino C, Nucara A, Panzera MF, Pietrafesa M (2023) Greenhouse gas balance in the city of Reggio Calabria and assessment of the effects of measures of emission reduction and absorption. *Energies* 16(9):3615. <https://doi.org/10.3390/en16093615>
- Masson-Delmotte V, Zhai P, Pirani S, Connors C, Péan S, Berger N, Caud Y, Chen L et al (2021) Summary for policymakers. In: *Climate change 2021: the physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY
- Mayer H, Höppe P (1987) Thermal comfort of man in different urban environments. *Theoret Appl Climatol* 38(1):43–49. <https://doi.org/10.1007/BF00866252>
- Melidis M, Russel DJ (2020) Environmental policy implementation during the economic crisis: an analysis of European member state’ leader-laggard’ dynamics. *J Environ Planning Policy Manage* 22(2):198–210. <https://doi.org/10.1080/1523908X.2020.1719051>
- Mobaraki A, Oktay Vehbi B (2022) A conceptual model for assessing the relationship between urban morphology and sustainable urban form. *Sustainability* 14(5):2884. <https://doi.org/10.3390/su14052884>
- Mouratidis K, Yiannakou A (2022) What makes cities livable? Determinants of neighborhood satisfaction and neighborhood happiness in different contexts. *Land Use Policy* 112:105855. <https://doi.org/10.1016/j.landusepol.2021.105855>
- Nicolas C, Kim J, Chi S (2021) Natural language processing-based characterization of top-down communication in smart cities for enhancing citizen alignment. *Sustain Cities Soc* 66:102674. <https://doi.org/10.1016/j.scs.2020.102674>
- Nieuwenhuijsen MJ (2021) New urban models for more sustainable, liveable and healthier cities post covid19; reducing air pollution, noise and heat island effects and increasing green space and physical activity. *Environ Int* 157:106850. <https://doi.org/10.1016/j.envint.2021.106850>
- Nightingale AJ, Gonda N, Eriksen SH (2022) Affective adaptation= effective transformation? Shifting the politics of climate change adaptation and transformation from the status quo. *Wiley Interdisciplinary Reviews: Climate Change* 13(1):e740. <https://doi.org/10.1002/wcc.740>
- Nita IA, Sfiică L, Voiculescu M, Birsan MV, Micheu MM (2022) Changes in the global mean air temperature over land since 1980. *Atmospheric Research* 279:106392. <https://doi.org/10.1016/j.atmosres.2022.106392>
- Qiao Y, Xu W, Wu D, Meng C, Qin L, Li Z, Zhang X (2022) Changes in the spatiotemporal patterns of dry/wet abrupt alternation frequency, duration, and severity in Mainland China, 1980–2019. *Science of The Total Environment* 838:156521. <https://doi.org/10.1016/j.scitotenv.2022.156521>
- Ramyar R, Ackerman A, Johnston DM (2021) Adapting cities for climate change through urban green infrastructure planning. *Cities* 117:103316. <https://doi.org/10.1016/j.cities.2021.103316>

- Renn O, Lucas K (2022) Systemic risk: the threat to societal diversity and coherence. *Risk Anal* 42(9):1921–1934. <https://doi.org/10.1111/risa.13654>
- Shu Z, Chan PW, Li Q, He Y, Yan B (2021) Characterization of daily rainfall variability in Hong Kong: a nonlinear dynamic perspective. *Int J Climatol* 41:E2913–E2926. <https://doi.org/10.1002/joc.6891>
- Simpson NP, Mach KJ, Constable A, Hess J, Hogarth R, Howden M et al (2021) A framework for complex climate change risk assessment. *One Earth* 4(4):489–501. <https://doi.org/10.1016/j.oneear.2021.03.005>
- Sohail MT, Ullah S, Majeed MT, Usman A (2021) Pakistan management of green transportation and environmental pollution: a nonlinear ARDL analysis. *Environ Sci Pollut Res* 28(23):29046–29055. <https://doi.org/10.1007/s11356-021-12654-x>
- Su Y, Wu J, Ciais P, Zheng B, Wang Y, Chen X, Li X, Li Y, Wang Y, Wang C, Jiang L, Laforzezza R (2022) Differential impacts of urbanization characteristics on city-level carbon emissions from passenger transport on road: evidence from 360 cities in China. *Build Environ* 219:109165. <https://doi.org/10.1016/j.buildenv.2022.109165>
- Sulhan OF, Sevik H, Isinkaralar K (2023) Assessment of Cr and Zn deposition on *Picea pungens* Engelm. in urban air of Ankara, Türkiye. *Environ Dev Sustain* 25(5):4365–4384. <https://doi.org/10.1007/s10668-022-02647-2>
- Suping Z, Guanglin M, Yanwen W, Ji L (1992) Study of the relationships between weather conditions and the marathon race, and of meteorotropic effects on distance runners. *Int J Biometeorol* 36(2):63–68. <https://doi.org/10.1007/BF01208915>
- Teodoro AC, Duarte L (2013) Forest fire risk maps: a GIS open source application—a case study in Norwest of Portugal. *Int J Geogr Inf Sci* 27(4):699–720. <https://doi.org/10.1080/13658816.2012.721554>
- Thom EC (1959) The discomfort index. *Weatherwise* 12(2):57–61. <https://doi.org/10.1080/00431672.1959.9926960>
- Tran TV, Bruce D, Huang CY, Tran DX, Myint SW, Nguyen DB (2023) Decadal assessment of agricultural drought in the context of land use land cover change using MODIS multivariate spectral index time-series data. *Giscience Remote Sensing* 60(1):2163070. <https://doi.org/10.1080/15481603.2022.2163070>
- Twinomuhangi R, Sseviiri H, Mulinde C, Mukwaya PI, Nimusiima A, Kato AM (2021) Perceptions and vulnerability to climate change among the urban poor in Kampala City. *Uganda Regional Environmental Change* 21(2):1–13. <https://doi.org/10.1007/s10113-021-01771-5>
- UNFCCC (2022) Adaptation Knowledge Portal. Available online: <http://www4.unfccc.int/sites/NWP/Pages/Home.aspx> (accessed on 10 February 2022).
- Wang ZH (2022) Reconceptualizing urban heat island: beyond the urban-rural dichotomy. *Sustain Cities and Soc* 77:103581. <https://doi.org/10.1016/j.scs.2021.103581>
- Wang J, Zhou W, Wang J (2019) Time-series analysis reveals intensified urban heat island effects but without significant urban warming. *Remote Sensing* 11(19):2229. <https://doi.org/10.3390/rs11192229>
- Wardekker A (2021) Contrasting the framing of urban climate resilience. *Sustainable Cities and Society* 75:103258. <https://doi.org/10.1016/j.scs.2021.103258>
- Wardekker A, Lorenz S (2019) The visual framing of climate change impacts and adaptation in the IPCC assessment reports. *Clim Change* 156(1–2):273–292. <https://doi.org/10.1007/s10584-019-02522-6>
- Xiao Y, Zhong JL, Zhang QF, Xiang X, Huang H (2022) Exploring the coupling coordination and key factors between urbanization and land use efficiency in ecologically sensitive areas: a case study of the Loess Plateau China. *Sustain Cities Soc* 86:104148. <https://doi.org/10.1016/j.scs.2022.104148>
- Yabe T, Rao PSC, Ukkusuri SV, Cutter SL (2022) Toward data-driven, dynamical complex systems approaches to disaster resilience. *Proc Nat Acad Sci* 119(8):e2111997119. <https://doi.org/10.1073/pnas.2111997119>
- Yang H, Lee T, Juhola S (2021) The old and the climate adaptation: climate justice, risks, and urban adaptation plan. *Sustainable Cities and Society* 67:102755. <https://doi.org/10.1016/j.scs.2021.102755>
- Yi X, Jue W, Huan H (2021) Does economic development bring more livability Evidence from Jiangsu Province China. *J Clean Prod* 293:126187. <https://doi.org/10.1016/j.jclepro.2021.126187>
- Zhang X, Han L, Wei H, Tan X, Zhou W, Li W, Qian Y (2022) Linking urbanization and air quality together: a review and a perspective on the future sustainable urban development. *J Clean Prod* 346:130988. <https://doi.org/10.1016/j.jclepro.2022.130988>
- Zhang Y, Zhou R, Chen J, Gao X, Zhang R (2023) Spatiotemporal characteristics and influencing factors of air pollutants over port cities of the Yangtze River Delta. *Air Quality, Atmosphere & Health* 1–14. <https://doi.org/10.1007/s11869-023-01397-y>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.